On-Road Mobile Source PM and Black Carbon Emission Rates

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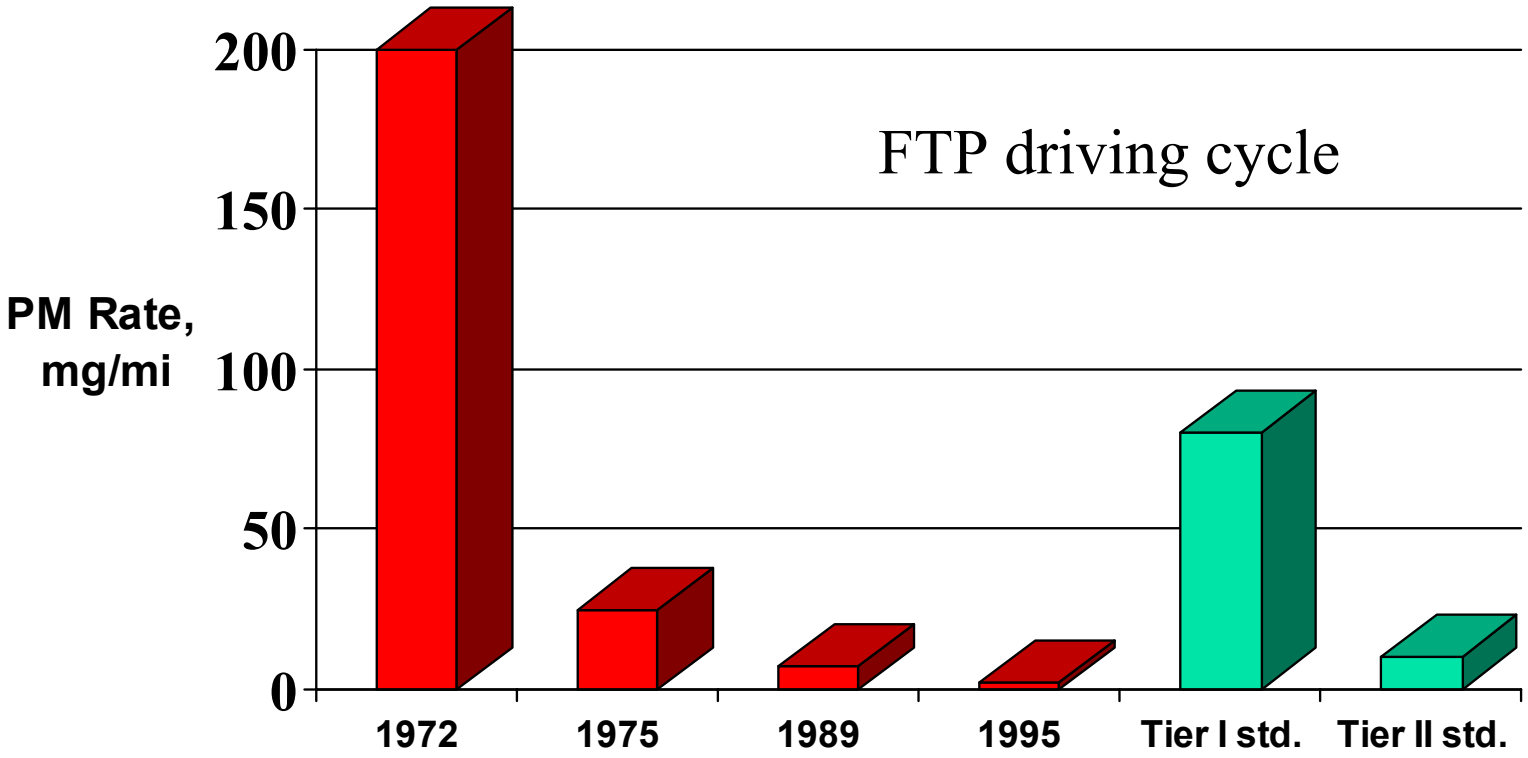
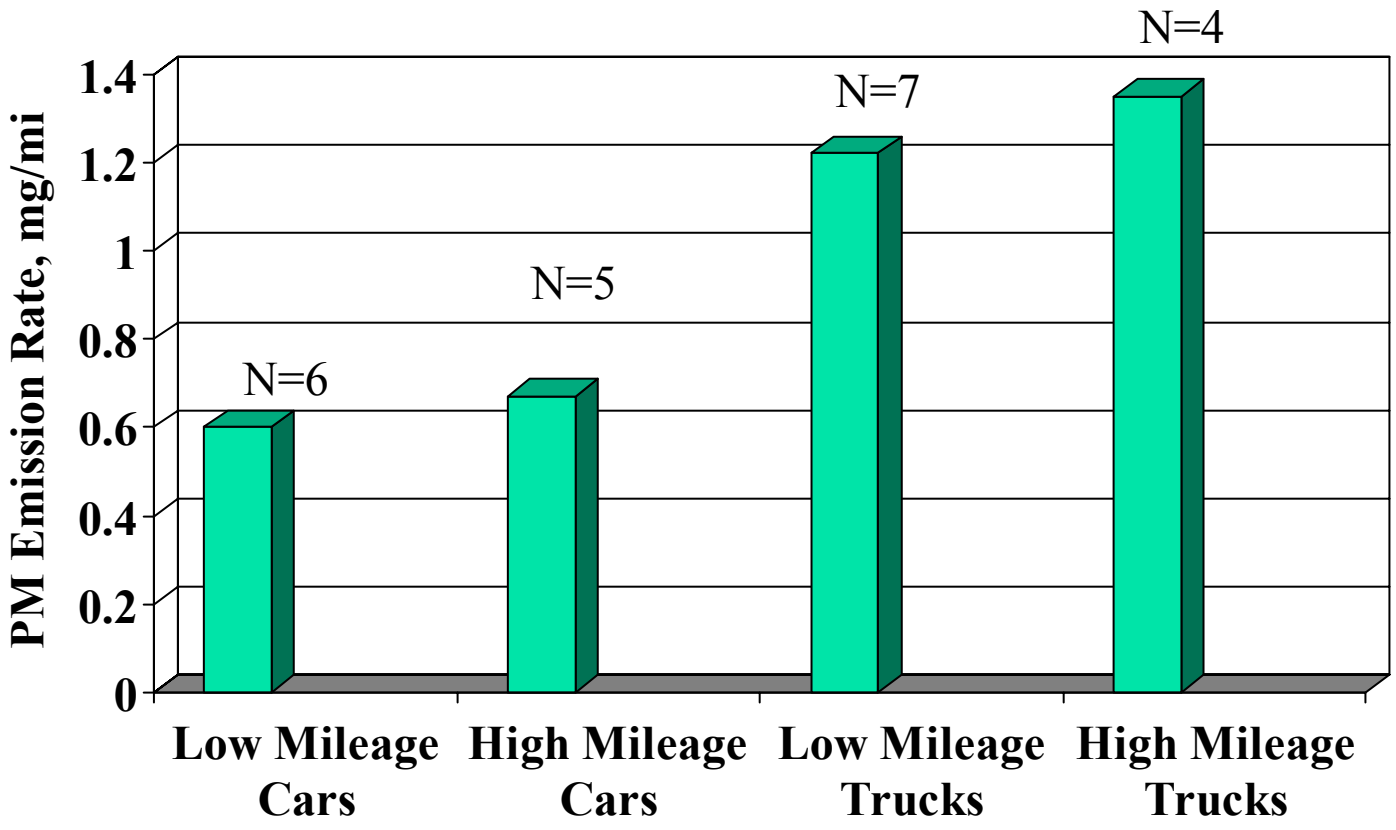
Overview

- Mobile sources are a significant urban source of PM
  - Exhaust
  - Tire wear
  - Brake wear
  - Re-entrained road dust
- Emission are a function of:
  - Technology
    - Gasoline, diesel, two-stroke, DI gasoline
    - Emission control devices
  - Vehicle maintenance
  - Driving cycle
  - Fuel
  - Ambient conditions

Historical PM Emission Rates for Properly Functioning Light-Duty Gasoline Vehicles



ERC Study of FTP Exhaust PM Emissions from Properly-Functioning 1994-1998 Gasoline Vehicles

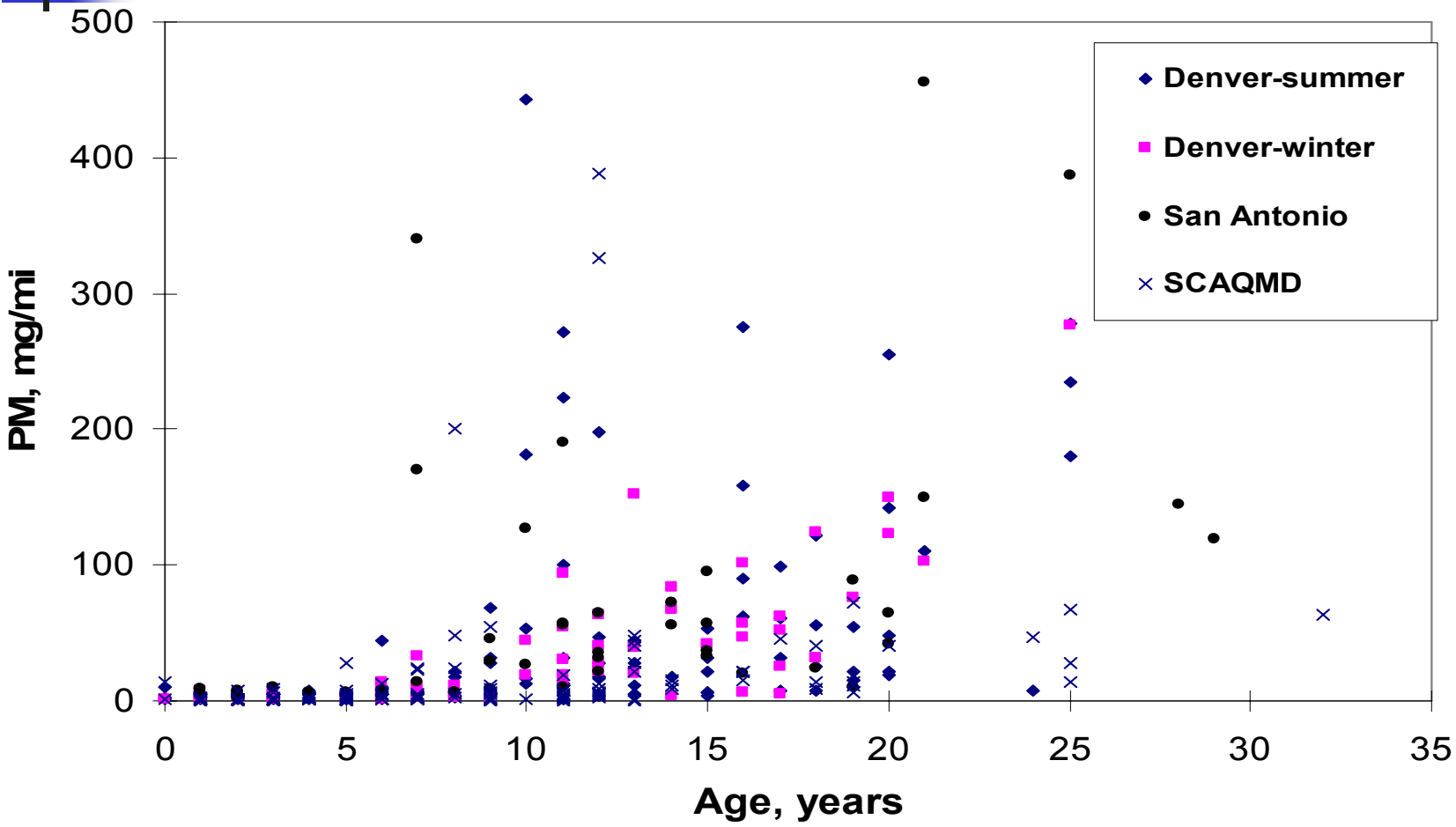


Vehicles operated on CA phase 2 gasoline

Measurement Issues

- PM mass operationally defined
  - Semi-volatiles
  - Filter adsorption of organics
- Black carbon
  - Generally not measured (except some smoke meter data)
  - OC/EC operationally defined
    - Thermal/optical methods
    - Vacuum oven method for OC
    - OC by extraction
  - Are optical measurements of black carbon needed?

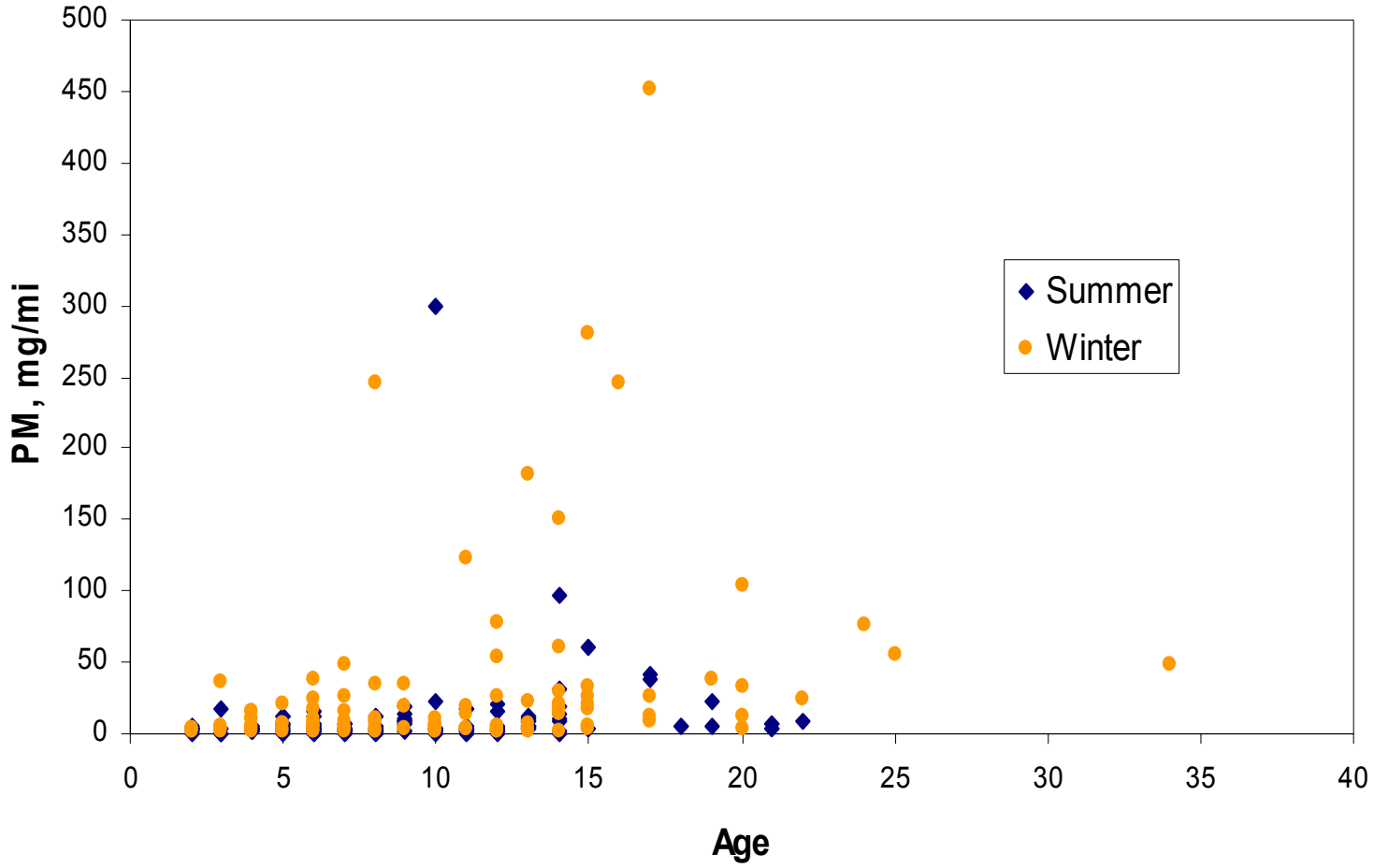
CRC E-24: Age Distribution of PM Emission Rates for Light-Duty Gasoline Vehicles (1997 and older)



Percent of Total Carbon Present as Elemental Carbon in E-24 Study

Category	Denver	San Antonio	SCAQMD
1991-97	39	47	63
1986-90	29	26	20
1981-85	30	27	27
Pre-1981	14	36	21
Smokers	11	7	ND

Light-Duty Gasoline Vehicle IM240 PM_{10} Emission Rates (1999 Central Carolina Study)

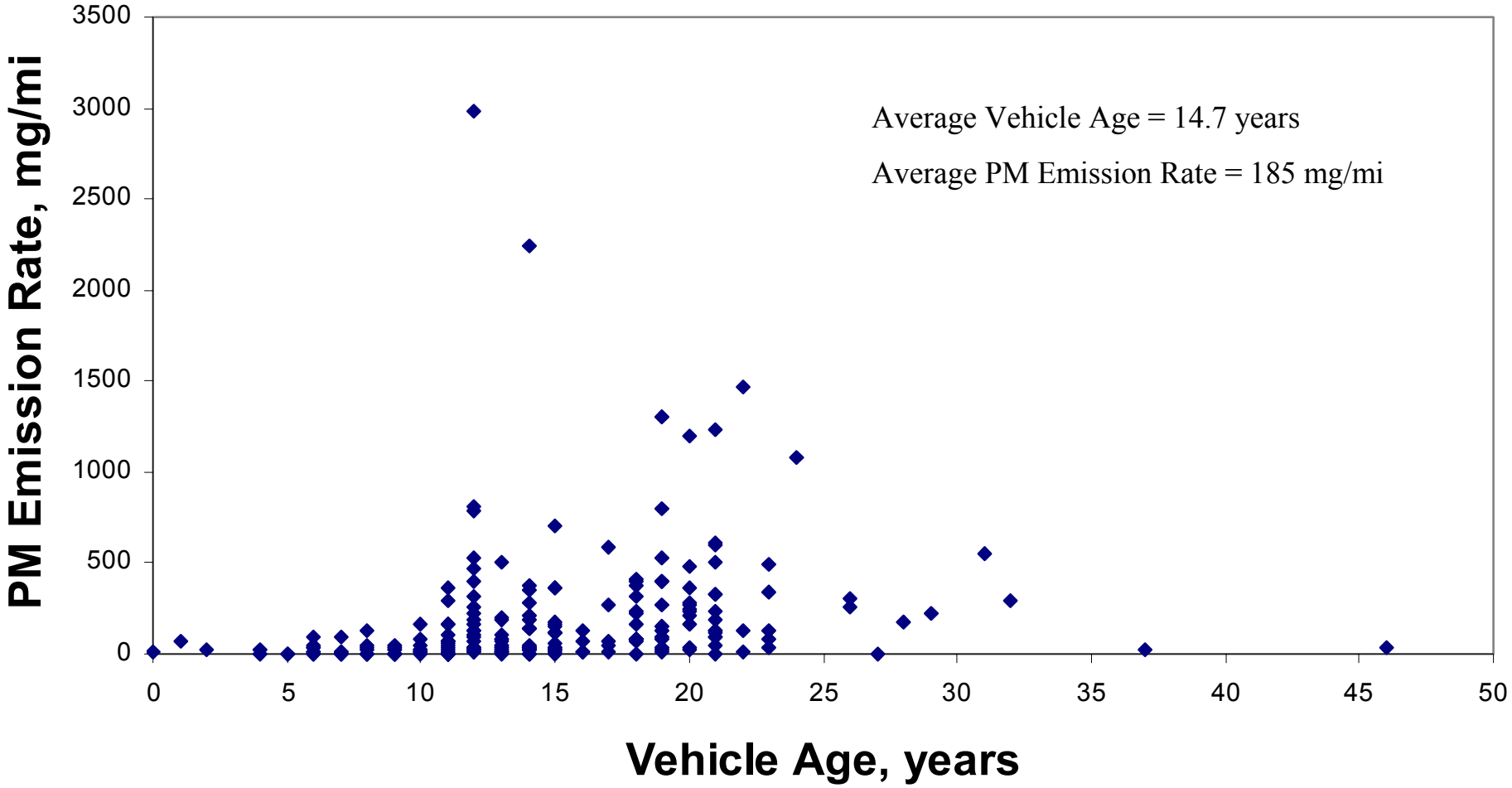


Percent EC in the Central Carolina Study

PM Emission Rate	% of TC present as EC
3.0 – 5.99	26.2
6.0 – 15.9	21.8
16.0 – 33.9	29.9
34 - 58	18.6
59 - 339	18.4

- No cold start emissions

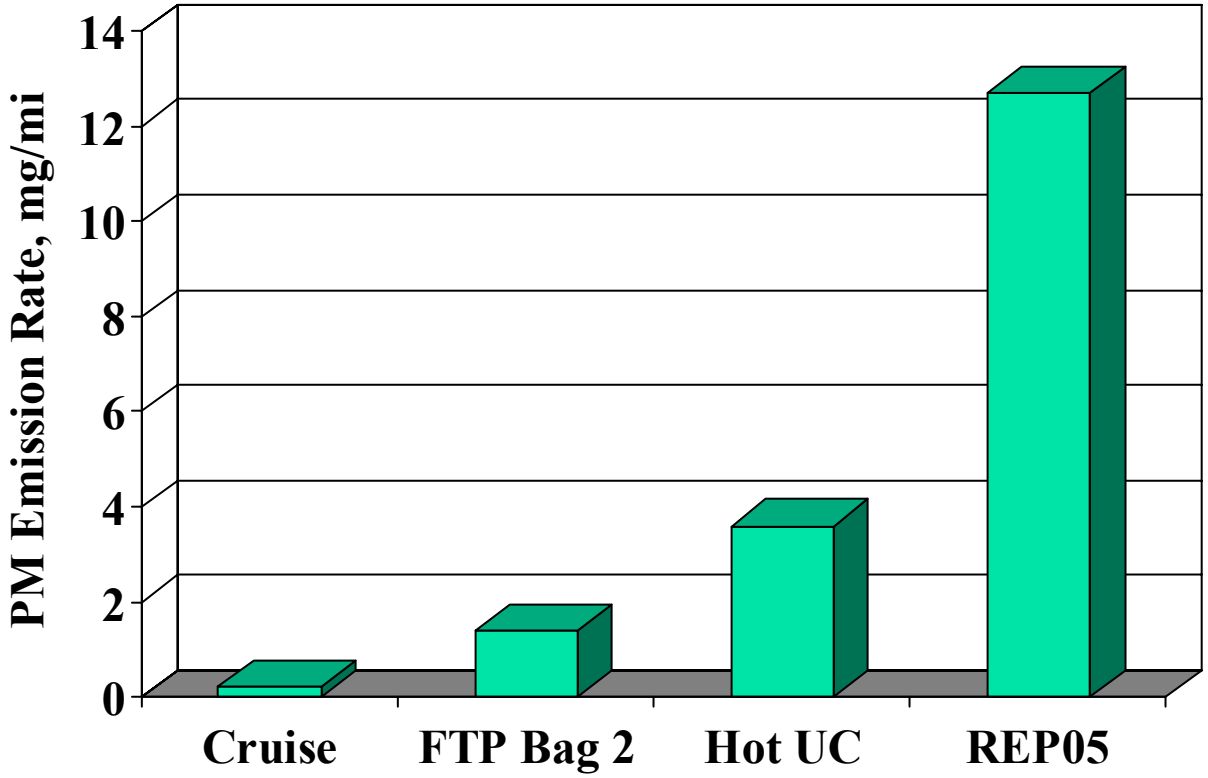
PM10 Emission Rates from 1999 EPA Juarez, Mexico Study



Kansas City Study

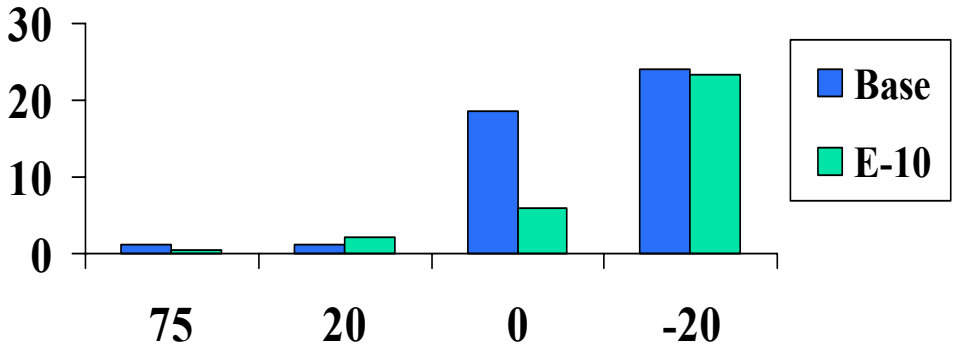
- EPA, CRC, DOE-NREL, DOT and state and local agencies through EIIP are funding a study on in-use light-duty gasoline PM emissions
- Well characterized vehicle recruitment
- 480 vehicles tested on the EPA transportable dynamometer using the LA92 Unified Driving Cycle in 2004/2005 (summer and winter phases)
- Objectives
  - Identify the distribution of PM emissions in the vehicle fleet
  - Identify the fraction of PM high emitters in the vehicle fleet
  - Evaluate and improve existing mobile source PM inventories and models
- Summer phase completed

Effect of Driving Cycle on Hot Stabilized PM10 Emission Rates from Properly Functioning, Tier 0 and Tier 1 Light-Duty Gasoline Vehicles

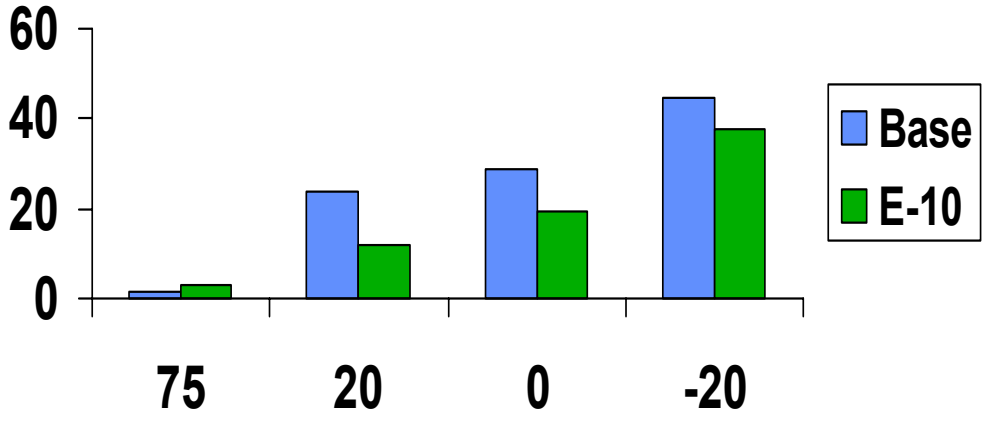


Effect of Low Temperature on FTP Exhaust PM Emission Rates, mg/mi

1994 Aspire

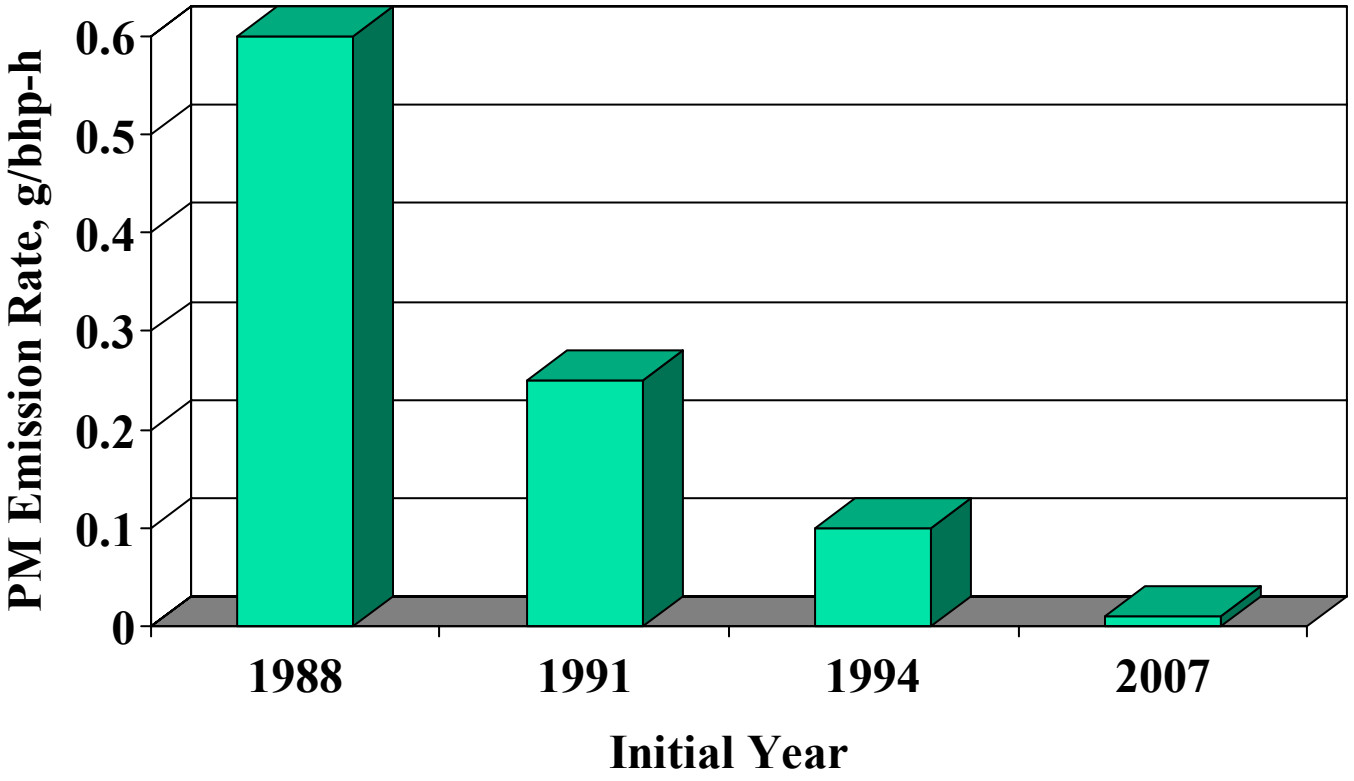


1989 Celebrity

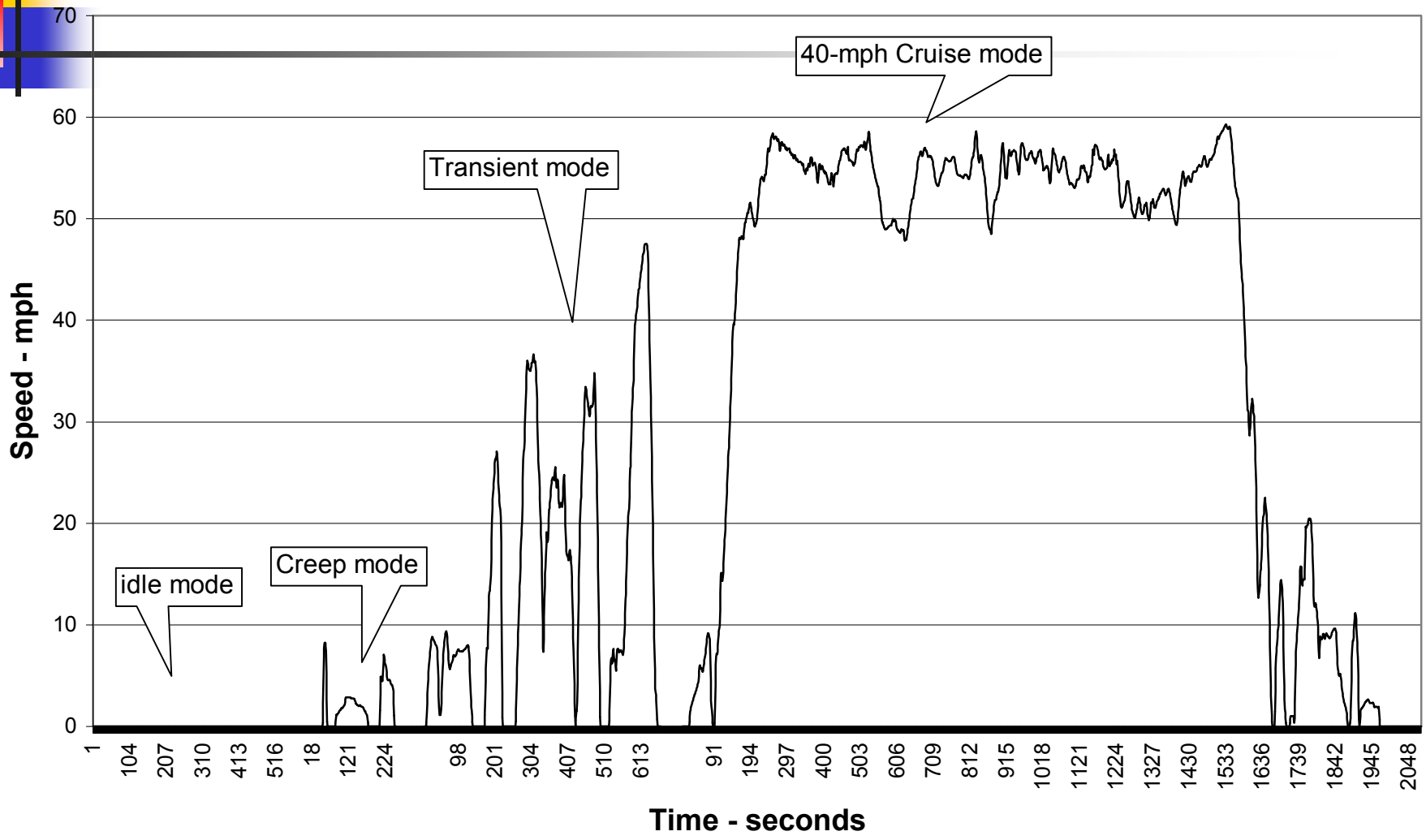


Temperature, °F

Heavy Heavy Duty Diesel Vehicle Emission Standards in the U.S.

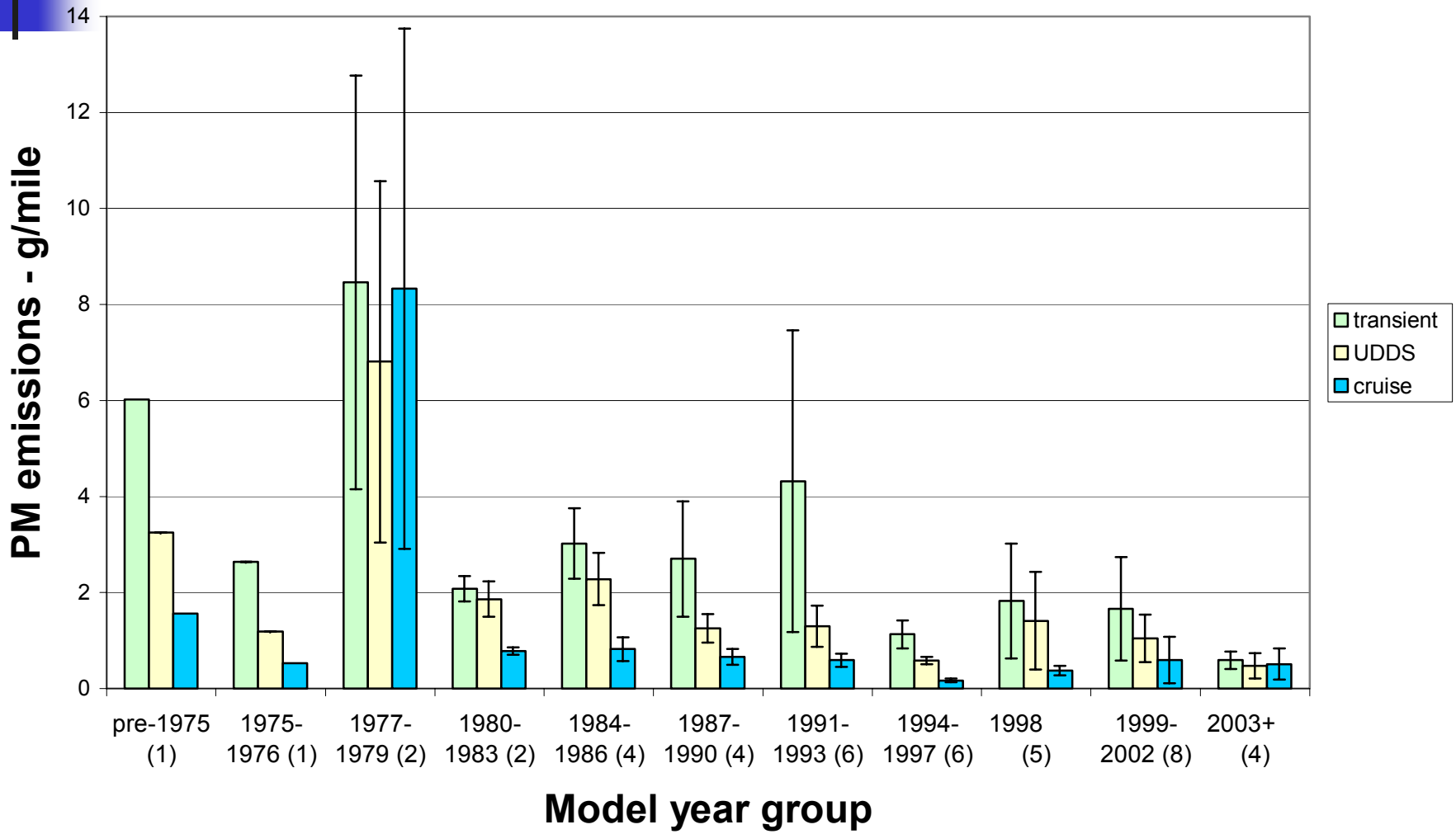


ARB HHDDT 4-mode cycle



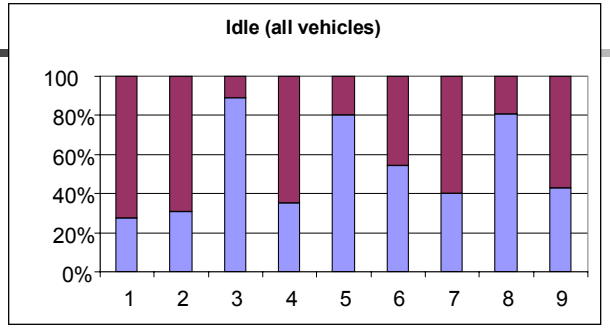
Slide courtesy Hector Maldonado, CARB

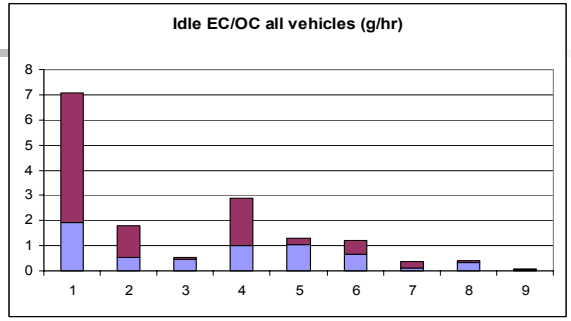
Average PM Emissions

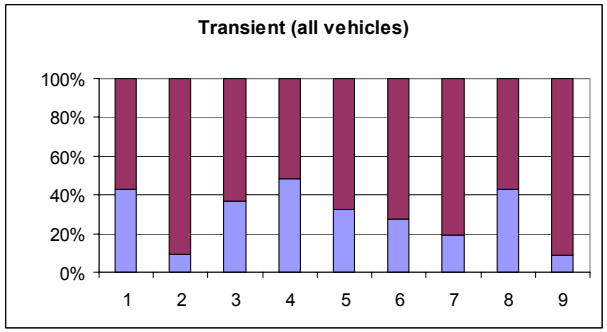


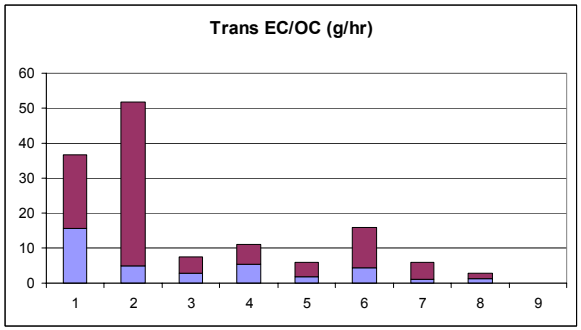
Slide courtesy Hector Maldonado, CARB

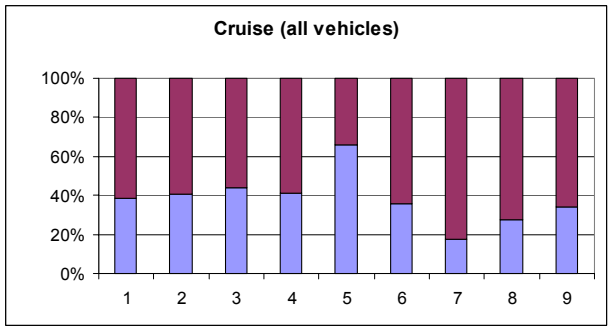
EC/OC Ratios for HDDVs in CRC E-55/59

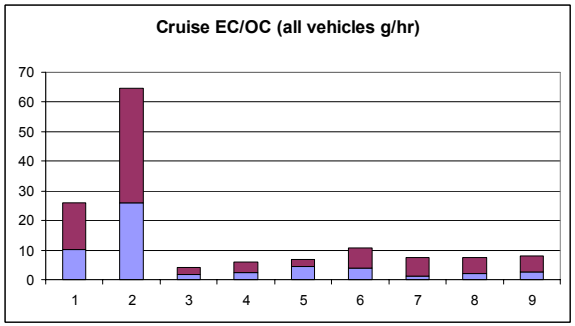












1 1985
2 1989
3 1994
4 1995
5 1995
6 2000
7 2004
8 2004
9 1998 (MHD)

red - EC

blue - OC

TC highly correlated with mass (Teflon filter):
TC = 1.01*mass + 0.02
R^2 = 0.98

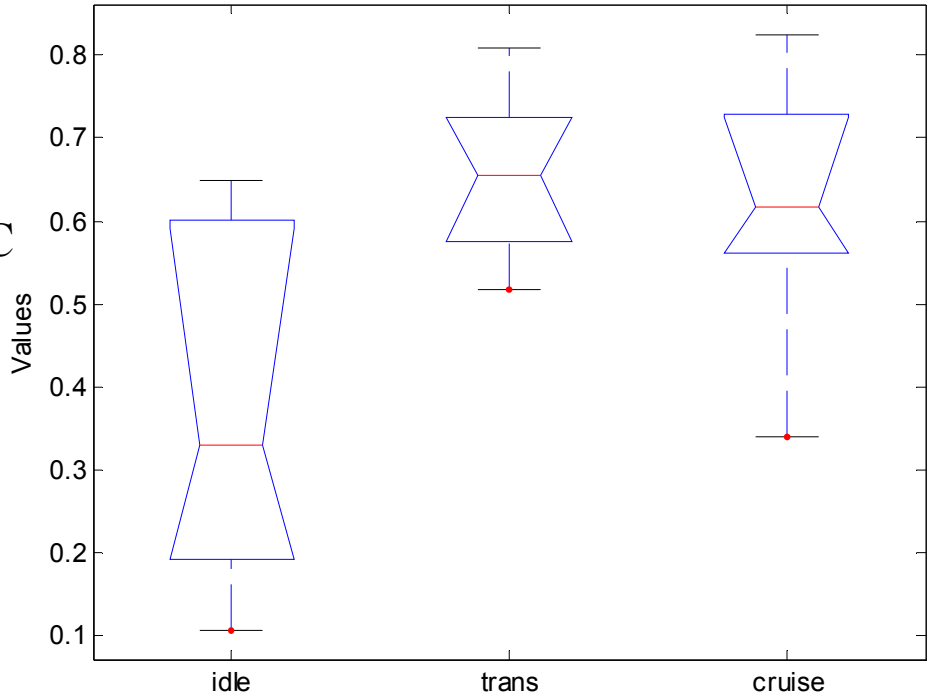
Slide courtesy of William Vance, CARB

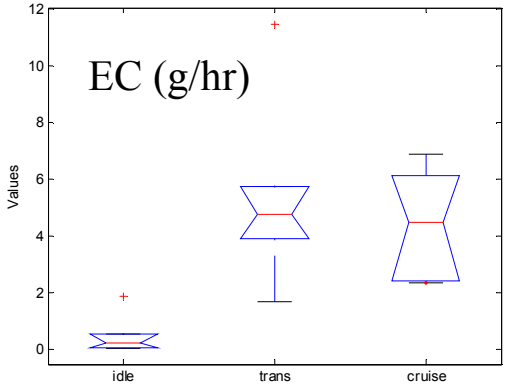
EC/TC Ratios and EC Emission Rates for Idle, Transient and Cruise Operation

- idle ratio < trans/cruise ratio

Median EC/TC with 95% confidence intervals
median (idle, trans, cruise) = (0.33, 0.65, 0.62)
Excluded 2 1980's and 1 MHD

EC/TC





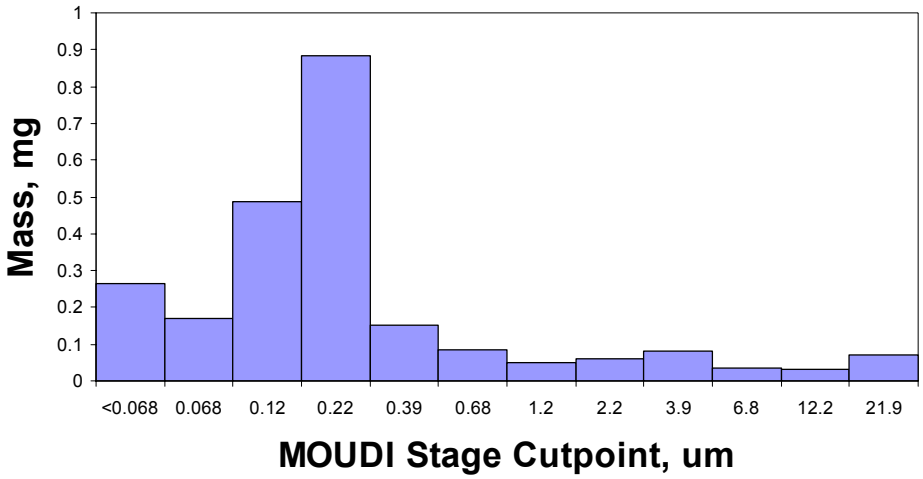
The lower and upper lines of the "box" are the 25th and 75th percentiles of the sample.

The notches in the box are a graphic 95% confidence interval about the median

Slide courtesy of William Vance, CARB

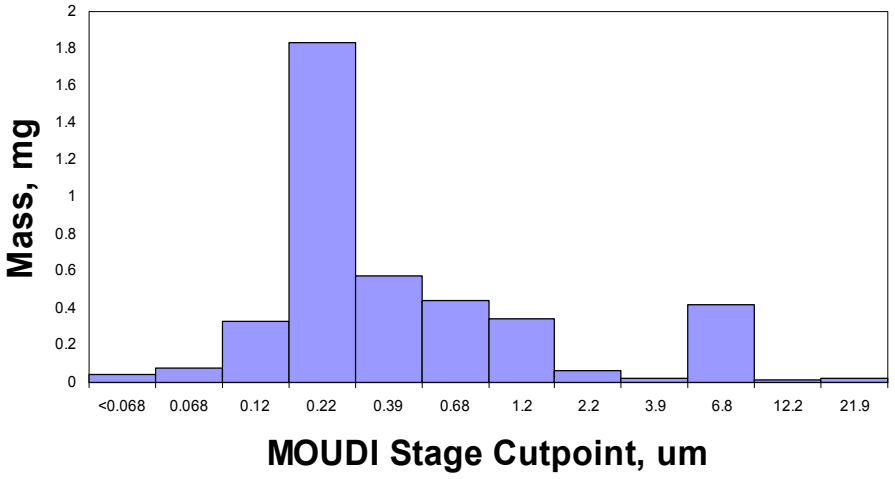
MOUDI Impactor Particle Size Mass Distributions

Gasoline Vehicle



1979 Ford Fairmont

Diesel Vehicle



1984 Volkswagen Rabbit

DOE Gasoline/Diesel PM Split Study

- Ambient samples collected in the SCAQMD June-July 2001
- Source samples collected May-September 2001
  - 59 light-duty vehicles tested on the UC
  - 32 heavy-duty vehicles tested on 5 cycles
- Chemistry performed by DRI and Univ. of Wisconsin-Madison
- Source profiles to be created and source apportionment will be performed on the ambient samples

PM Emissions from Tire Wear

- Average tire-wear rate is approximately 50 mg/tire/mile – i.e. 200 mg/mi for passenger vehicles and higher for HD vehicles
- Most of the tire-wear PM is large particles.
- Few studies on tire wear PM size distribution. Summary of results suggest 5-6% of the PM is in the PM10 size range.
- EPA uses an emission rate of rate of 2 mg/mi per tire for PM10
- Wear rates dependant on driving mode
- European commission estimates 5% of tire wear PM smaller than 1 um

Composition of Tire Wear PM

- Composition of PM very similar to bulk tread composition
- Approximate bulk composition of tread:
  - 40% polymer
  - 40% carbon black or other fillers
  - 18% oil (high aromatic content)
  - Other (S, Zn, etc.)

Brake Wear Emissions

- Engineering estimates of brake wear range from 18 mg/mi for small vehicles to 47 mg/mi for a large pickup truck
- Laboratory studies suggest 30% of the wear is in the PM10 size range (i.e. 5 to 14 mg/mi)
- Brake wear emission rates from asbestos and metallic brake pads estimated by EPA at 13 mg/mi for PM10

Brake Pad Composition

- Many different formulations in use
- Composition:
  - Fibers (metallic, mineral, ceramic, aramid)
  - Binder (Phenolic resin)
  - Fillers (Barium sulfate, clays, metal powders, ground rubber, cashew dust,etc.)
  - Friction modifiers (graphite, carbon black, etc.)

Example Brake Pad Composition Based on MSDS Information

Phenolic resin	5-10%
Copper fiber	10-15%
Aramid fiber	2-7%
Potassium titanate	25-30%
Antimony sulfide	2-7%
Zirconium oxide	5-10%
Barium sulfate	15-20%
Calcium hydroxide	2-7%
Cashew dust	5-10%
Graphite	5-10%

Is there a need to determine the optical absorption of brake wear PM?

Re-entrained Road Dust

- Emission rates highly variable
  - Road surface (paved/unpaved)
  - Road surface silt (<75 um particles)
  - Particle size
  - Average weight of vehicles
  - Vehicle speed
  - Moisture
- EPA Part 5 estimate: 35 mg/mi PM10 for light-duty vehicles
- Inventory generally felt to overestimate re-entrained road dust
- Includes tire wear, brake wear, and road surface wear (asphalt)

Synopsis

- Exhaust PM emissions have decreased markedly for both on-road gasoline and diesel vehicles
- PM emissions do not come from exhaust alone.
- For the current gasoline light-duty fleet PM_{10} emission rates are roughly 15 mg/mi from exhaust, 10 mg/mi for brake wear, 8 mg/mi for tire wear and 35 mg/mi for re-entrained road dust
- Light-duty vehicle black carbon emissions could be 4 mg/mi from exhaust, 1mg/mi from brakes, 3 mg/mi from tire wear
- Exhaust PM emissions inventories are uncertain due to the skewed distribution of emissions and poor data on the effect of other variables

Synopsis

- More in-use HDD data are needed to estimate exhaust BC emission rates
- The implementation of particle traps on 2007 and later model year HDD vehicles will greatly reduce BC emissions
- The impact of particle trap retrofit programs will need to be factored into the inventory as well